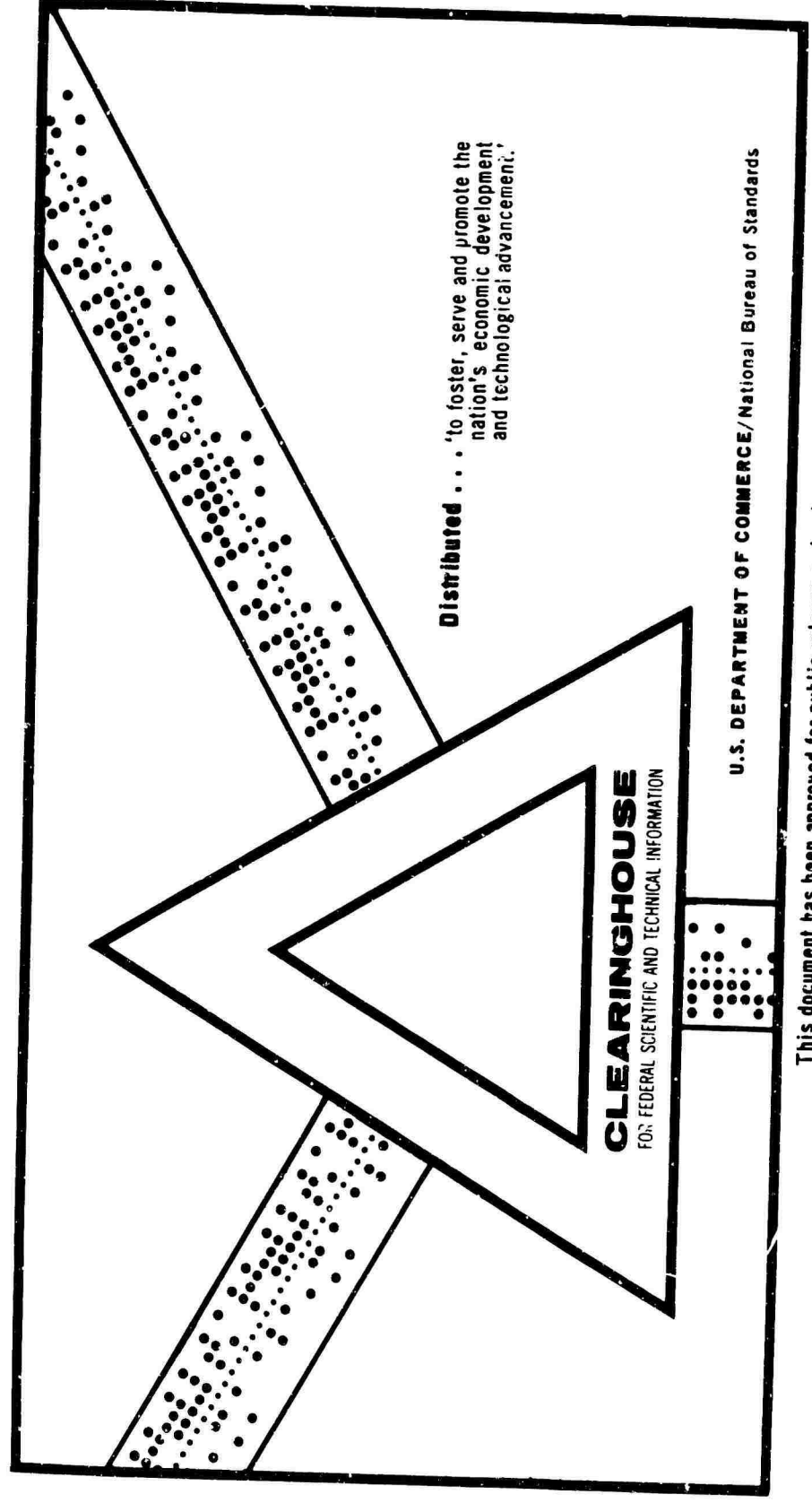


CORE MANAGEMENT PLAN FOR THE MH-1A

Shrinivas S. Iyer, et al

Army Engineer Reactors Group
Fort Belvoir, Virginia

3 October 1969



ENGINEERING DIVISION
U.S. ARMY ENGINEER REACTORS GROUP
CORPS OF ENGINEERS
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SHRINIVAS S. IYER
RALPH S. SAUNDERS

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ABSTRACT

This study analyzes the fuel cycle costs of the MH-1A for two core management plans. The calculated cost figures are based on the most current data. Each plan includes the core refueling and cost schedules over the life of the plant. The cost schedules are intended to serve as support data for determining funding requirements.

Finally, comparison is made of the two plans with regard to total cost, cost per fiscal year, and cost per kilowatt-hour of electrical energy produced.

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I. BACKGROUND

The MH-1A type II core design was changed from a 2-year out-in shuffle to a 3-year batch core reload. Since the original MH-1A core management plans and fuel cycle cost analysis (Engineering Support Study dated 22 Dec 1967) were based on a 2-year shuffle type II core, it was necessary to update the core management plans and fuel cycle costs to reflect the change in the final core design.

II. INTRODUCTION

The MH-1A Core Management and Cost Analysis Study, dated 22 Dec 1967, describes five possible core management plans for the MH-1A. A core management plan is intended to predict the fuel cycle costs associated with a nuclear power plant. Only costs associated with the initial core and subsequent refueling cores are considered.

As of 1 July 1969, two core management schemes are being considered by USAERG, both of which differ from those investigated in the 67 study. These two plans, referred to hereafter as plan A and plan B, are presented in this report.

III. MANAGEMENT PLANS

1. Plan A: Plan A is essentially the same as plan I of the 1967 core management study, differing only in the refueling schedules (ref 1). Plan A uses type I cores, which are consumed at 15 month intervals (ref 2). The breakdown is as follows; core life is 12 full-power months, which yields 13.5 months of operation when divided by a plant load factor of .89, and 1 1/2 months of downtime is added for refueling.

During each refueling operation only one-half of the core fuel elements are replaced. The inner 16 elements are removed, the outer 16 are transferred to the inner half of the core, and 16 fresh

elements are placed in the outer half of the core. Hence, the type I core is termed a shuffled core.

As a consequence of shuffling, each half core spends 24 full power months in the reactor, i.e., 12 months in the outer half and 12 in the inner half. Exceptions are the inner half of the first core, which is withdrawn during the first refueling, and the last refueling core, which is removed rather than shuffled.

The control rods are replaced during every other refueling, and are intended to last 24 full-power months (ref 3). Table I is a schedule of refueling cores and control rod sets which will be required for the approximately 20-year life of the plant. The schedule commences with the completion date of the first refueling operation which is currently determined to be 1 Dec. 1969.

2. Plan B: Plan B involves a core and control rod design quite different from that of plan A, and consequently a different refueling schedule as well. This core will be referred to as a type II core; but should not be confused with the type II core discussed in the 67 core management study, which is of a different design. Plan B involves the use of type I cores of plan A until the fourth refueling, after which type II cores are used. The type II core is a batch-loaded core, that is, during each refueling all 32 elements are replaced. The core lifetime is 140 full-power weeks (ref 4). With a plant load factor of 0.89, the normal operating core life is increased to 36 months. One month is allotted to refueling time.

The control rod life matches core life and control rods are replaced during each refueling.

Table II is a schedule of core loading according to plan B.

IV. FUEL CYCLE COST EQUATIONS

The fuel cycle cost equation, as it applies to Army operated nuclear power plants, has been discussed in reference 1. The terms of the equation consist of fuel fabrication costs, reprocessing costs, depletion charges, shipping costs, and use or interest charges.

For the MH-1A, fuel cycle costs may be divided into two groups according to the time of their occurrence. One group, which will be called the initial cost, consists of those costs which arise before the fuel enters the reactor. The other group is made up of

TABLE I
Plan A Core-Loading Schedule
Type I Core

Core Number	Control Rod Set	Half Core		Start of Operation	End Operation
		Inner	Outer		
2	1	1a	2	1 Dec 69	15 Jan 71
3	2	2	3	1 Mar 71	15 Apr 72
4	2	3	4	1 Jun 72	15 Jul 73
5	3	4	5	1 Sep 73	15 Oct 74
6	3	5	6	1 Dec 74	15 Jan 76
7	4	6	7	1 Mar 76	15 Apr 77
8	4	7	8	1 Jun 77	15 Jul 78
9	5	8	9	1 Sep 78	15 Oct 79
10	5	9	10	1 Dec 79	15 Jan 81
11	6	10	11	1 Mar 81	15 Apr 82
12	6	11	12	1 Jun 82	15 Jul 83
13	7	12	13	1 Sep 83	15 Oct 84
14	7	13	14	1 Dec 84	15 Jan 86
15	8	14	15	1 Mar 86	15 Apr 87
16	8	15	16	1 Jun 87	15 Jul 88
17	9	16	17	1 Sep 88	15 Oct 89

TABLE II
Plan B Core-Loading Schedule

Core Number	Control Rod Set	Half Core		Start of Operation	End of Operation
		Inner	Outer		
2	1	1a	2	1 Dec 69	15 Jan 71
3	2	2	3	1 Mar 71	15 Apr 72
4	2	3	4	1 Jun 72	15 Jul 73
5	3	5	5	1 Sep 73	1 Sep 76
6	4	6	6	1 Oct 76	1 Oct 79
7	5	7	7	1 Nov 79	1 Nov 82
8	6	8	8	1 Dec 82	1 Dec 85
9	7	9	9	1 Jan 86	1 Jan 89

costs which occur only after the fuel has been discharged, and will be referred to as the final cost.

a. Initial Cost: The initial cost is expressed as,

$$IL = F + IF + T$$

where,

IL = total initial cost, in dollars

F = core fabrication cost, in dollars

IF = fabrication use charge, in dollars

T = shipping cost, in dollars

b. Final Cost: The final cost of a core is computed from,

$$FL = D + R + T$$

where,

FL = total final cost, in dollars

D = depletion charge, in dollars

R = reprocessing cost, in dollars

T = shipping cost, in dollars

c. Fabrication Cost: The cost of fuel fabrication includes conversion of UF_6 to UO_2 , and fabrication into the finished fuel assemblies. Fabrication cost is taken as 150 dollars per kilogram Uranium (ref 1) or,

$$F = 150 \times KI$$

where KI is the beginning of life uranium loading in Kg.

d. Reprocessing Cost: At the end of core life the spent fuel is discharged for reprocessing to recover valuable uranium and plutonium. To date, USAERG has shipped all spent fuel cores to the government's Savannah River laboratory for reprocessing, and will continue to do so during the foreseeable future.

I. By agreement, USAERG pays SRNL an estimated reprocessing charge at the time that spent fuel is shipped. The exact reprocessing

charge is later computed by SRNL. The difference between the estimated and adjusted figures is made up in subsequent payment by, or credit to, USAERG. To arrive at a reprocessing charge estimate, the 67 core management study assumes that all irradiated fuel is reprocessed by Nuclear Fuel Services (NFS) of West Valley, New York. The same source is used to estimate the reprocessing costs in the report.

In this case, the reprocessing cost consists of the NFS reprocessing cost and the charge for converting uranyl nitrate to UF_6 . NFS plant charges are \$31,000 per day with an allowable throughput in kg per day based on enrichment (ref 1 and Table III).

II. Of this \$22,500 is the reprocessing charge, and the remainder is a "per unit turn-around charge" (ref 2).

NFS charges a minimum turn-around fee of \$188,000 per fuel lot (ref 3). This amounts to a penalty charge for small fuel lots. SRNL can store spent fuel for the Army (as it is currently doing) until a sufficiently large lot is obtained to make reprocessing economical, with no storage charge to USAERG. Therefore, the effect of the minimum turn-around charge is deleted in estimating the reprocessing cost. It is assumed that the fact that SRNL stores spent fuel for an undetermined period of time does not affect the timing or amount of the reprocessing cost.

The AEC accepts the processed uranium as uranyl nitrate and adds a charge of \$5.60 per KgU for conversion to UF_6 (ref 3). The AEC assumes that 1 percent of the uranium delivered for reprocessing is lost in reprocessing (ref 4). The reprocessing cost is then,

$$R = 31000 \times KF/A + .99 \times 5.60 \times KF$$

or,

$$R = (31000/A + 5.54) \times KF$$

where,

KF = the end of life core loading in KgU

A = NFS allowable throughput, in Kg/day

TABLE III

Allowable Throughput in the NFS Reprocessing Plant*

Initial Enrichment	Allowable Throughput **
(w/o)	(kgU/day)
3	1000
4	880
5	740
6	650
7	590
8	540
9	500

* Data taken from Reference 1

** For enrichments not specifically listed use linear interpolation between two nearest values.

e. Depletion Charge: It is necessary to pay the AEC only for the value of the fuel burned (plus whatever is lost in reprocessing), the rest is returned. At the same time credit is given for fissile plutonium produced during irradiation. The AEC currently guarantees \$9.28 per gram of fissile plutonium (ref 1). The depletion charge is the burnup charge less the amount of the plutonium credit.

The burnup charge is the difference between the value of the uranium loading at beginning of core life (UI) and the value at end of life (UF). The value of the uranium loading at any time is determined by the mass of the uranium present and its enrichment, and is based on the AEC Schedule of Base Charges and Standard Table of Enriching Services (ref 2). The initial fuel value is,

$$UI = KI \times (OI + SI)$$

where,

KI = initial loading, in KgU

OI = the cost in \$/KgU of the fresh feed required to produce the desired enrichment

SI = the cost in \$/KgU of separative work to produce the desired enrichment

A similar equation gives the final fuel value.

$$UF = .987 \times KF \times (OF + SF)$$

where KF is the end life loading and OF and SF are the corresponding values of fresh feed and enrichment charge. The end of life loading is reduced by 1.3 percent to allow for losses in reprocessing and conversion (ref 1).

The AEC assumes that 1 percent of the plutonium present at shutdown is lost during reprocessing (ref 2). Therefore the plutonium credit is,

$$V = .99 \times KP \cdot 9280$$

or,

$$V = 9190 \times KP$$

where KP is the amount of fissile plutonium present at shutdown in Kg.

It is expected that after 31 Dec 1970, the AEC will replace the guaranteed credit for plutonium with a figure based on competitive demand (ref 3). At this time it is not possible to predict what the value of plutonium will be or the effect of the change on depletion charges.

An expression for the depletion charge is,

$$D = (UI - UF) - V$$

f. Shipping Cost: Shipping costs arise whenever a newly fabricated core is shipped to the MH-1A and when spent cores are discharged for reprocessing. The mobile nature of the MH-1A makes estimating an average shipping cost for the life of the plant difficult. To this end however, a one-way distance of 6000 miles by sea plus 1500 miles by land with rates of 2 cents per ton-mile by sea and 4 cents per ton-mile by rail are assumed (ref 1). Four elements may be shipped in one shipping cask and the total weight is 13 tons (ref 2). The weight of the empty cask on the return trip is 12.5 tons.

Shipping costs are computed as,

$$T = 13x(.02x6000+.04x1500) \times N + 12.5x(.02x6000+.04x1500) \times N$$

$$T = 4590 \times N$$

where N is the number of shipping casks required to ship the core.

g. Use Charges: The AEC currently charges interest on all nuclear fuel leased at a rate which will be 7 1/2 percent per annum as of 1 Nov 69 (Ref 6). Government agencies, such as USAERG, are not required to pay use charges on leased fuel inventories. As far as the MH-1A is concerned, use charges arise only when the uranium is under the control of private industries, viz., during fabrication.

The fabrication use charge is,

$$IF = .075 \times UI \times TF$$

where TF is the fabrication time and is taken as 4 months for half cores, and 6 months for whole cores (ref 4).

V. DATA AND CALCULATIONS

Tables IV and V contain all of the data necessary to predict the costs of fueling the MH-1A using either plan A or plan B. The estimates are obtained from a straightforward application of the equations to the data. The results are contained in tables VI and VII in thousands of dollars.

TABLE IV

Data for Calculation of Fuel Cycle Cost of Plan A *

Core Designation	1b	1a	2-16	17
KI	1465	1465	1465	1465
KF	1455	1450	1441	1446
KP	1.5	4.2	5.9	2.6
OI	177.97	204.65	204.65	204.65
SI	174.31	209.00	209.00	209.00
OF	144.40	144.40	149.92	183.95
SF	131.49	131.49	138.45	182.06
A	959	959	945	852
N	4	4	4	4
TF	6/12	6/12	4/12	4/12

* Core loading data is taken from reference 4, pg. 2-4.

TABLE V

Data for Calculation of Fuel Cycle Costs of Plan B

Core Designation	1b	1a	2&3	4	5-9
KI	1465	1465	1465	1465	2640
KF	1455	1450	1441	1446	2528
KP	1.5	4.2	5.9	2.6	11.8
OI	177.97	204.65	204.65	204.65	317.31
SI	174.31	209.00	209.00	209.00	359.52
OF	144.40	144.40	149.92	183.95	236.37
SF	131.49	131.49	138.45	182.06	250.82
A	959	959	945	852	709
N	4	4	4	4	8
TF	6/12	6/12	4/12	4/12	6/12

TABLE VI

Fuel Cycle Costs of Plan A, in K\$

Core Designation	1b	1a	2-16	17
UI	516.1	606.0	606.0	606.0
UF	396.2	394.8	410.0	522.4
V	13.8	38.6	34.2	54.2
D	106.1	172.6	141.7	59.7
F	219.8	219.8	219.8	219.8
R	55.1	54.9	55.3	55.3
T	18.4	18.4	18.4	18.4
IF	19.4	22.7	15.2	15.2
IL	257.6	260.9	258.4	253.4
FL	179.6	245.9	215.4	138.7

TABLE VII
Fuel Cycle Costs of Plan B, in K\$

Core Designation	1b	1a	2&3	4	5-9
UI	515.1	606.0	606.0	606.0	1786.8
UF	396.2	394.8	410.1	522.4	1215.6
V	13.8	38.6	54.2	23.9	108.4
D	106.1	172.6	141.7	59.7	463.8
F	219.8	219.8	219.8	219.8	396.0
R	55.1	54.9	55.3	60.6	124.5
T	18.4	18.4	18.4	18.4	36.8
IF	19.4	22.7	15.2	15.2	67.0
IL	257.6	260.9	253.4	253.4	499.8
FL	179.6	245.9	215.4	138.7	624.1

In addition to the fuel costs, there is the cost of supplying the core with control rods. This cost is \$500,000 per control rod set of type I, and \$300,000 per control rod set of type II (ref 1). The cost of a zero power test of the first core of type II is \$50,000 and must be included as part of the initial cost of core 5 (see plan B loading schedule).

VI. COST SCHEDULES

By combining the fuel costs as they are contained in tables VI and VII with their respective refueling schedule, the amounts and times of occurrence of the necessary core expenditures for the MH-1A may be predicted. In constructing a cost schedule it is assumed that the initial costs of core occur 24 months prior to the shutdown date for the refueling in which that core enters the reactor. This represents the minimum allowable lead time for core procurement, and is the latest date at which the initial cost may occur. At the same time, it is assumed that the final cost of a particular core occurs 13 months after the startup date following the refueling during which the core is discharged. This represents the minimum allowable lag time, and is the earliest date at which the final cost may occur. Fuel cost schedules for the MH-1A are shown in tables VIII and IX.

It will be noted that the scheduling assumptions result in considerable "lumping" of fuel expenditures in table IX. This might present a difficulty in funding were it not that initial costs may be shifted to any date earlier than scheduled and the final costs to any date later, with no increase in the amount of the expenditure.

Initial costs may be considered to have been spent through core 4, and the first final cost, that of core 1b, does not occur until Nov 1970. Therefore, the cost schedules of both plan A and plan B commence with fiscal year 71.

VII COST COMPARISON

The total cost of fueling the MH-1A for fiscal years 71 through 90 is \$10,589,400 by plan A, and \$8,164,500 using plan B. Amortizing these totals over the time involved yields average cost per fiscal year figures of \$529,470 for plan A and \$408,225 for plan B. According to these figures, switching to a type II core in plan B yields a fuel savings for the life of the plant of 22.9 percent.

TABLE VIII
Cost Schedule for Plan A*

Fiscal Year	Expenditure	Date of Occurrence	Amount K\$
71	FL 1b	1 Jan 71	179.6
72	IL 5	15 Sep 71	253.4
	CR 3		500.0
	FL 1a	1 Apr 72	245.9
73	IL 6	15 Oct 72	253.4
74	FL 2	1 Jul 73	215.4
	IL 7	15 Jan 74	253.4
	CR 4		500.0
75	FL 3	1 Oct 74	215.4
	IL 8	1 Apr 75	253.4
76	FL 4	1 Jan 76	215.4
77	IL 9	15 Jul 76	253.4
	CR 5		500.0
	FL 5	1 Apr 77	215.4
78	IL 10	15 Oct 77	253.4
79	FL 6	1 Jul 78	215.4
	IL 11	15 Jan 79	253.4
	CR 6		500.0
80	FL 7	1 Oct 79	215.4

* Under expenditure: IL - initial cost
FL - final cost
CR - control rod cost

TABLE VIII (CON'T)

Fiscal Year	Expenditure	Date of Occurrence	Amount K\$
80	IL 12	15 Apr 80	253.4
81	FL 8	1 Jan 81	215.4
82	[IL 13	15 Jul 81	253.4
	CR 7		500.0
	FL 9	1 Apr 82	215.4
83	IL 14	15 Oct 82	253.4
84	[FL 10	1 Jul 83	215.4
	IL 15	15 Jan 84	253.4
	CR 8		500.0
85	[FL 11	1 Oct 84	215.4
	IL 16	15 Apr 85	253.4
86	FL 12	1 Jan 86	215.4
87	[IL 17	15 Jul 86	253.4
	CR 9		500.0
	FL 13	1 Apr 87	215.4
88			
89	FL 14	1 Jul 88	215.4
90	FL 15	1 Oct 89	215.4
91	[FL 16	1 Jan 91	215.4
	FL 17		138.7
Total Fuel & Control Rod Cost			10589.4

TABLE IX

Cost Schedule For Plan B*

Fiscal Year	Expenditure	Date of Occurrence	Amount K\$
71	FL 1b	1 Jan 70	179.6
72	IL 5	15 Jul 71	499.8
	Zero Power Test		
	OF 5		50.0
	CR 3		300.0
	FL 1a	1 Apr 72	245.9
73			
74	FL 2	1 Jul 73	215.4
75	IL 6	1 Sep 74	499.8
	CR 4		300.0
	FL 3	1 Oct 74	215.4
	FL 4		138.7
76			
77			
78	IL 7	1 Oct 77	499.8
	CR 5		300.0

* Under expenditures: IL - Initial Cost
FL - Final Cost
CR - Control Rod Cost

TABLE IX (CON'T)

Fiscal Year	Expenditure	Date of Occurrence	Amount K\$
78	FL 5	1 Nov 77	624.1
79			
80			
81	[IL 8	1 Nov 80	499.8
	CR 6		300.0
	FL 6	1 Dec 80	624.1
82			
83			
84	[IL 9	1 Dec 83	499.8
	CR 7		300.0
	FL 7	1 Jan 84	624.1
85			
86			
87	FL 8	1 Feb 87	624.1
88			
89			
90	FL 9	1 Mar 90	624.1
Total Fuel & Control Rod Cost			8164.5

A more reliable basis for comparison of type I and type II cores is the cost per kilowatt-hour of electrical energy produced. To this end, the cost of the fuel in the reactor from core number 5 to the end of plant life is divided by the total electric energy produced during the same time interval. A plant output of 45Mw thermal (full power), and efficiency of 22.2 percent are assumed. The results are,

type I 8.37 mills/ Kwh

type II 6.11 mills/ Kwh

The type II cost represents a decrease of 27.0 percent of the type I cost.

An examination of the elements of the fuel costs shows that the savings of plan B are due to the lower fuel fabrication and control rod costs of the type II core, which are further reduced when amortized over the greater core life. On the other hand, the reprocessing costs are greater for the type II core, as might be expected from the higher enrichment and less efficient burnup.

VIII CONCLUSIONS

This study has analyzed the fuel cycle costs of the MH-1A for refueling plans involving two types of cores. Plan B has been shown to be more economical for the life of the plant than plan A, representing a savings of 27.0 percent over plan A.

Cost schedules for each plan have been included to provide a basis for determining funding requirements.

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